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DISCUSSION OF PILE FOUNDATIONS FOR LARGE TOWERS ON PERMAFROST

(Published in November, 1951)

By Harry Carlson, and L. A. Nees

STRUCTURAL DIVISION

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DISCUSSION

HARRY CARLSON,[3] A. M. ASCE.—The author has described tests and studies which are of great interest and importance to engineers designing pile foundations for sites in arctic and subarctic regions where permafrost composed of frost-susceptible soil is present.

It is assumed from the statements under the heading, "Test Program; Test Results," describing Fig. 2, that curves 1 to 5, inclusive, indicate the results of tests on wet wood and curve 6 indicates the results of tests on $1\frac{1}{4}$-in. steel pipe. It has been observed that the adhesive force between wood and various soils increases as the temperature decreases.[4] This would account for the behavior of the clayey soils in curves 1 and 3 as well as the silty soils in curves 2 and 4, respectively. The sandy loam soil of curve 5 also falls in the same area of the graph as the clayey and silty soils at the 11°F to 15°F temperature range. The adhesive force developed between soils and steel or wood depends, among other things, on the surface characteristics of the pile materials. Taper in the proper direction or surface roughness on wood piles could be more effective in developing adhesive force than the relatively smooth surface of steel pipe. It is not indicated in the paper what type of failure occurred in the tests made on the steel pipe; that is, whether the pipe slipped in the frozen soil or whether a diagonal tension failure occurred in the soil. It would be interesting to know what results would be obtained from tests on full-size pile specimens and whether the indicated unit adhesive force is affected by the diameter and depth of imbedment of the pile specimen in frozen ground.

Although the structural loads and other factors may have prevented the use of wood piles in the case described the heat transferred into the ground by wood piles would be much less than that transferred by steel piles. This is evident from the coefficients of thermal conductivity of these materials—0.8 for wood and 312.0 for steel. The quantity of heat conveyed into the ground by a pile is a function of its thermal conductivity and cross-sectional area. A 12-in. wood pile would give a $(k\,A)$-value of $0.8 \times 113 = 91$. An 8-in. XXH steel pipe pile would have a $(k\,A)$-value of $312 \times 21.4 = 6{,}677$. Thus, for a given temperature differential and length of pile, the steel pipe would transmit about seventy-five times as much heat as the wood pile.

In the design of the heat diverter pad shown in Fig. 5, it is indicated that a compacted dry sand backfill is used between the concrete pad and the permafrost table. As it would be undesirable to transmit heat from the pad to the permafrost in the vicinity of the piles, a less conductive material than a compacted sand should be used if possible. Generally, the coefficient of thermal conductivity of materials varies in direct proportion to the density. Thus, for the least heat transfer, fill materials with low density should be selected.

NOTE.—This paper by L. A. Nees was published in November, 1951, as *Proceedings-Separate No. 103*. The numbering of footnotes in this Separate is a continuation of the consecutive numbering used in the original paper.

[3] Chf., Permafrost Div., St. Paul District, Corps of Engrs., U. S. Dept. of the Army, St. Paul, Minn.

[4] "Permafrost or Permanently Frozen Ground and Related Engineering Problems," by S. W. Muller, J. W. Edwards, Inc., Ann Arbor, Mich., 1947.

A fill, containing material with a high void content which is saturated and frozen, will have a high volumetric latent heat of fusion and will be very effective in resisting heat transfer until the ice is entirely melted.

Filling of the steel pipe piles with relatively high-density materials such as sand and concrete will tend to increase the total quantity of heat flowing down the pile. It appears that the central part of the concrete pad bounded by the piles is unnecessary since only the part outside the pile circle is effective in dissipating heat laterally to areas where it will not affect the permafrost adjacent to the piles. Since the coefficient of thermal conductivity of the concrete in the pad would generally be nearly the same as the soil on which it rests, it would be desirable to use a material in the pad having a much larger coefficient of thermal conductivity than the supporting soil, or lateral heat transfer would not be effected.

Under the heading, "Reduction of Heat Transmission; *e* Required Length of Pile,"—"* * * the minimum pile imbedment was assumed to be 30 ft based on an allowable rate of melting of 1 ft per day for 30 consecutive days." Thus, the adfreezing strength of the pile could be zero at the end of the thawing season. As refreezing normally would occur from the ground surface downward, uplift forces could develop with ice segregation in frost-susceptible soils near the surface before refreezing would occur at lower levels. It would be desirable, therefore, to provide sufficient anchorage to resist uplift in the annual frost zone. Normally piles cannot be driven into permafrost but must be placed in holes formed by drilling or steaming operations. By attaching or forming anchors at the bottom of the pile it is possible to increase the resistance to withdrawal very substantially over that obtained by the bond developed from the adfreezing strength.

L. A., NEES,[5] A. M. ASCE.—The increase in adhesive force between wood and soil, as temperature decreases, accounts for the difference between curves 1 and 3 and curves 2 and 4 of Fig. 2, as stated by Mr. Carlson. The curve relationships further imply that, except for soils that differ widely in classification, the soil type may have only a minor effect on adhesive force—at least at lower temperature ranges. These factors do not invalidate the opinion expressed by the writer that the test values ranged lower than was expected. In no case—even on tests discarded because of doubt as to the results—did any of the values of u reach 125 lb per sq in. Only two tests exceeded 100 lb per sq in.—one at 102 lb per sq in. and the other at 121 lb per sq in. The remainder were observed well below 100 lb per sq in.

During and immediately after each test run, a careful examination of the soil mass was made to obtain evidence of shear failure. In no case except that of very dry soil conditions (M less than 6%) did the soil fail in shear. All other failures consisted of slippage of the pipe in the soil. The writer recognizes that the dividing line for the two types of failure in terms of moisture content will depend on the type of pile material used, all other variables being held constant.

The writer has not as yet been able to make the necessary series of full-scale tests which would answer questions on scaling.

[5] Chf., Installations Eng. Section, Air Installations Div., Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio.

Mr. Carlson's comments regarding the thermal efficiency of wood piles are pertinent. The use of wood piles was considered in the design; however, the tower loadings and site conditions dictated the use of steel piles.

The sand-blanket backfill was used to reduce the volume of gravel required, gravel being scarce. Actually, a coarse gravel might be more desirable. The 18-in. insulating layer was counted on to provide the major portion of the thermal resistance.

Whether to fill the pile or to cap it, leaving it hollow, is open to question and would probably reflect the individual judgment of the designer. The thermal disadvantages and structural advantages of filled piles are not of major importance.

The central part of the pad is unnecessary and the diverter was designed on that basis. However, the pad was made continuous over the area to decrease the danger of surface-water infiltration.

As described in the paper, the diverter employs copper for an average radius of 3 ft. It thus provides against the contingencies that Mr. Carlson describes. In the basic design, values of $k = 1.0$ for concrete and 0.33 for soil were used. The analysis on this basis indicated that concrete cannot deliver sufficient heat laterally until a radius of the order of 3 ft to 5 ft is established. This necessitated the use of the copper sheet.

It is true that refreezing normally occurs from the ground surface downward. However, when air temperatures go below freezing the heat flow is reversed. The tower is now a structure capable of dissipating tremendous quantities of heat energy. For the design conditions, the frictional resistance of the unfrozen length of pile is approximately 25 kips, which is sufficient to hold forces developed by surface freezing to a depth of approximately 1 ft. No analysis was made, but it was intuitively concluded that, before this could be exceeded, the pile bottom would be "refrozen" into the permafrost for a sufficient depth to overcome forces developed by surface freezing. However, in any specific design where serious doubts exist regarding this condition, the designer can either adopt Mr. Carlson's suggestion of anchors, or increase the length of pile. Anchors may prove most desirable for "steamed-in" piles. However, such anchors should have a diameter of at least three pile diameters to insure success. For "drilled-in" piles, it should prove more economical to increase the pile length.

The writer wishes to thank Mr. Carlson for his interesting discussion. It revealed the weak points in the paper and illustrated the need for more and extensive investigations into problems of this nature.

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